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(54) **POWDER METALLURGY WEAR-RESISTANT TOOL STEEL**

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(57) **ABSTRACT**

A powder metallurgy wear-resistant tool steel includes chemical components by mass percent of: V: 12.2%-16.2%, Nb: 1.1%-3.2%, C: 2.6%-4.0%, Si: ≤2.0%, Mn: 0.2%-1.5%, Cr: 4.0%-5.6%, Mo: ≤3.0%, W: 0.1%-1.0%, Co: 0.05%-0.5%, N: 0.05%-0.7%, with balance iron and impurities; wherein a carbide component of the powder metallurgy wear-resistant tool steel is an MX carbide with a NaCl type face-centered cubic lattice structure; wherein an M element of the MX carbide comprises V and Nb, and an X element comprises C and N.

6 Claims, No Drawings

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POWDER METALLURGY WEAR-RESISTANT TOOL STEEL

CROSS REFERENCE OF RELATED APPLICATION

This is a U.S. National Stage under 35 U.S.C. 371 of the International Application PCT/CN2015/091285, filed Sep. 30, 2015, which claims priority under 35 U.S.C. 119(a-d) to CN 201510250891.0, filed May 15, 2015.

BACKGROUND OF THE PRESENT INVENTION

Field of Invention

The present invention relates to tool steel, and more particularly to a powder metallurgy wear-resistant tool steel.

Description of Related Arts

Tool steel is widely used in manufacturing field. For a long service life of a tool made of the tool steel, the tool steel should be sufficient in wear resistance, impact toughness, bending strength and hardness. Under normal conditions of use, wear resistance determines the length of service life. Wear resistance of the tool steel depends on the matrix hardness, as well as content, morphology and particle size distribution of the second hard phase in the steel. The second hard phase in the steel comprises M_6C, M_2C, $M_{23}C_6$, M_7C_3 and MX carbides, wherein microhardness of the MX carbides are higher than other carbides, for providing better matrix protection during operation, thereby reducing wear and improving the service life of molds. Impact toughness and bending strength are key indicators of toughness. Coarse carbides in the steel will cause stress concentration, which reduces the toughness of the tool steel, resulting in fracture under a relatively low external load. In order to improve the toughness of the tool steel, it is important to reduce or refine the carbides. In order to avoid plastic deformation, hardness of the tool steel is usually required to be HRC60 or more.

Conventionally, the tool steel is mainly casted and forged by traditional production processes, wherein the tool steel prepared by casting and forging processes is limited by liquid steel which is slowly cooled during the processes. As a result, alloy components are easy to be segregated during consolidation and to form the coarse carbides. Even after subsequent forging and rolling processes, such bad structure will still adversely affect the performance of the alloy, resulting in low performances of the tool steal in strength, toughness, wear resistance and grinding performance, which is difficult to meet material performance and life stability requirements of high-end manufacturing. Tool steel prepared by a powder metallurgy method avoids the segregation problem of alloy elements, wherein the powder metallurgy method mainly comprises steps of: preparing powder by atomization, and forming the powder by consolidation. In the step of preparing powder by atomization, liquid steel is rapidly cooled into powder. Therefore, the alloy elements in the liquid steel are completely consolidated before segregation. A structure is fine and even after powder consolidation, wherein compared with casting and forging, alloy performance is significantly improved. Conventionally, only the powder metallurgy method is able to satisfy extremely high performance requirements of high alloy tool steel. Tool steel prepared by powder metallurgy has been reported, but components of some kinds of steel are not reasonably designed, so structure and performance should be further improved.

SUMMARY OF THE PRESENT INVENTION

An object of the present invention is to solve at least one of the above technical problems to some extent. Therefore, the present invention provides a powder metallurgy wear-resistant tool steel with excellent performances.

Accordingly, in order to accomplish the above objects, the present invention provides a powder metallurgy wear-resistant tool steel, comprising chemical components by mass percent of: V: 12.2%-16.2%, Nb: 1.1%-3.2%, C: 2.6%-4.0%, Si: ≤2.0%, Mn: 0.2%-1.5%, Cr: 4.0%-5.6%, Mo: ≤3.0%, W: 0.1%-1.0%, Co: 0.05%-0.5%, N: 0.05%-0.7%, with balance iron and impurities; wherein a carbide component of the powder metallurgy wear-resistant tool steel is an MX carbide with a NaCl type face-centered cubic lattice structure; wherein an M element of the MX carbide comprises V and Nb, and an X element of the MX carbide comprises C and N.

According to the powder metallurgy wear-resistant tool steel of an embodiment of the present invention, alloy components are designed for preparing a high wear-resistant tool steel, which is sufficient in impact toughness, bending strength and hardness. By adding a large amount of vanadium and carbon alloy elements, the MX carbide is formed, which improves wear resistance. Meanwhile, a certain amount of alloy elements such as chromium, molybdenum and silicon is added for strengthening a matrix and increasing a precipitation amount of the MX carbide. In the embodiment of the present invention, besides the alloy elements above, a certain amount of niobium and nitrogen alloy elements is added and solid dissolved in the MX carbide, so as to form a composite MX carbide comprising C, N, V and Nb. A type of the MX carbide is (V, Nb) (C, N), which increases a nucleation rate of the MX carbide, in such a manner that the MX carbide precipitated is finer and a toughness of the tool steel is improved. Adding amounts of niobium and nitrogen should be controlled within a proper range for preventing formation of highly stable carbides such as NbC, VN and NbN.

Preferably, in the chemical components of the powder metallurgy wear-resistant tool steel, a V equivalent is V_{eq}: 13.0%-16.0%, wherein $V_{eq}=V+0.65$ Nb.

Preferably, the impurities comprise O, wherein an O content is no more than 0.01%.

Preferably, the powder metallurgy wear-resistant tool steel comprises the chemical components by mass percent of: V: 13.0%-16.0%, Nb: 1.2%-2.5%, C: 2.8%-3.7%, Si: ≤1.3%, Mn: 0.2%-1.5%, Cr: 4.8%-5.4%, Mo: ≤2.0%, W: 0.1%-0.5%, Co: 0.1%-0.4%, N: 0.05%-0.4%, O: ≤0.008%, with balance iron and impurities.

Preferably, the impurities comprise S, wherein an S content is no more than 0.1%.

Preferably, the impurities comprise P, wherein a P content is no more than 0.03%.

Preferably, a volume fraction of the MX carbide is 16%-25%.

Preferably, a size of at least 80% of the MX carbide is 0.5-1.3 μm judging from volume percentage.

Preferably, a maximum size of the MX carbide is no more than 5.0 μm.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Preferred embodiments of the present invention are illustrated as follows. Examples of the embodiments are shown in drawings. The same or similar elements and the elements having same or similar functions are denoted by like reference numerals throughout the descriptions. The embodiments described herein with reference to drawings are explanatory, and used to generally understand the present disclosure, and not intended to be limiting.

The present invention provides a powder metallurgy wear-resistant tool steel with significant performances. According to the present invention, the powder metallurgy wear-resistant tool steel comprises chemical components by mass percent of: V: 12.2%-16.2%, Nb: 1.1%-3.2%, C: 2.6%-4.0%, Si: ≤2.0%, Mn: 0.2%-1.5%, Cr: 4.0%-5.6%, Mo: ≤3.0%, W: 0.1%-1.0%, Co: 0.05%-0.5%, N: 0.05%-0.7%, with balance iron and impurities; wherein a carbide component of the powder metallurgy wear-resistant tool steel is an MX carbide with a NaCl type face-centered cubic lattice structure; wherein an M element of the MX carbide comprises V and Nb, and an X element of the MX carbide comprises C and N.

According to the embodiments of the present invention, alloy components are designed for preparing a high wear-resistant tool steel, which is sufficient in impact toughness, bending strength and hardness.

Utilization of V is a key to improve wear resistance. V is a main element for forming the MX carbide, whose content is controlled between 12.2%-16.2%.

Nb and V have similar functions, both of which are involved in forming the MX carbide. According to the present invention, Nb is solved in the MX carbide for increasing a nucleation rate when the MX carbide is precipitated, so as to improve precipitating and refining of the MX carbide, and improve the wear resistance. An Nb adding limit prevents Nb-enriched MX carbide from precipitation. According to the present invention, a Nb content is controlled at 1.1%-3.2%.

C is one of the forming elements of the MX carbide, whose content is no less than 2.6% for ensuring that alloy elements are fully involved in carbide precipitation. A maximum C content is no more than 4.0% for avoiding that excessive C is solved in the matrix. When the above C content is controlled within 2.6%-4.0%, an optimized cooperation of wear resistance and toughness is obtained.

Si is not involved in carbide formation, but as a deoxidizing agent and a strengthening element of the matrix. Excessive Si will lower the toughness of the matrix, so a Si content is controlled at Si≤2.0%.

Mn is added as a deoxidizing agent, for fixing sulfur and reducing hot brittleness. In addition, manganese increases a quenching degree. According to the present invention, a Mn content is controlled within 0.2%-1.5%.

On one hand, Cr is solved in the matrix for improving hardness thereof, on the other hand, a small amount of Cr is solved in the MX carbide for promoting MX carbide precipitation. Therefore, a Cr content is 4.0%-5.6%.

Functions of Mo and W are similar to that of Cr. According to the embodiment of the present invention, a Mo content is Mo≤3.0%, and a W content is 0.1%-1.0%.

Co is mainly solved in the matrix for promoting carbide precipitation and refining particle size of the carbide. A Co content is 0.05%-0.5%.

N is involved in MX carbide formation. Under a rapid cooling condition, N promotes nucleation precipitation of the MX carbide while the MX carbide never excessively grows, which is conducive to improvement of the wear resistance. An N content is limited within 0.05%-0.7%.

According to the powder metallurgy wear-resistant tool steel of the embodiments of the present invention, by adding a large amount of vanadium and carbon alloy elements, the MX carbide is formed, which improves wear resistance. Meanwhile, a certain amount of alloy elements such as chromium, molybdenum and silicon is added for strengthening a matrix and increasing a precipitation amount of the MX carbide, so as to form a composite MX carbide comprising C, N, V and Nb. A type of the MX carbide is (V, Nb)(C, N), which increases a nucleation rate of the MX carbide, in such a manner that the MX carbide precipitation is finer and a toughness of the tool steel is improved. Adding amounts of niobium and nitrogen should be controlled within a proper range for preventing formation of highly stable carbides such as NbC, VN and NbN.

Preferably, in the chemical components of the powder metallurgy wear-resistant tool steel, a V equivalent is V_{eq}: 13.0%-16.0%, wherein V_{eq}=V+0.65 Nb.

Preferably, the impurities comprise O, wherein an O content is no more than 0.01%. Excessive O will lower the toughness of the tool steel. According to the embodiments of the present invention, the O content is no more than 0.01% for ensuring an outstanding steel performance.

Preferably, the powder metallurgy wear-resistant tool steel comprises the chemical components by mass percent of: V: 13.0%-16.0%, Nb: 1.2%-2.5%, C: 2.8%-3.7%, Si: ≤1.3%, Mn: 0.2%-1.5%, Cr: 4.8%-5.4%, Mo: ≤2.0%, W: 0.1%-0.5%, Co: 0.1%-0.4%, N: 0.05%-0.4%, O: ≤0.008%, with balance iron and impurities.

For obtaining a better combination performance, the chemical components of the powder metallurgy wear-resistant tool steel should be controlled within a certain range.

Preferably, the impurities comprise S, wherein a S content is no more than 0.1%.

Preferably, the impurities comprise P, wherein a P content is no more than 0.03%.

Preferably, a volume fraction of the MX carbide is 16%-25%.

Preferably, a size of at least 80% of the MX carbide is 0.5-1.3 μm judging from volume percentage.

Preferably, a maximum size of the MX carbide is no more than 5.0 μm.

According to the embodiments of the present invention, the powder metallurgy wear-resistant tool steel is prepared by a method comprising steps of:

a) preparing a liquid tool steal with the above components and loading the liquid tool steal into a ladle;

b) electrically heating covering slag at a top surface of the liquid steel in the ladle for maintaining superheat, injecting an inert gas from a hole at a bottom of the ladle for stirring the liquid steel;

c) moving the liquid steel into a tundish which is preheated through the guiding tube at the bottom of the ladle, adding covering slag to the top surface of the liquid steel when the liquid steel enters into the tundish and buries a bottom end face of the guiding tube;

d) continuously additional heating the tundish for maintaining the superheat;

e) moving the liquid steel into an atomization chamber from the tundish for atomization with an inert gas, wherein metal powder obtained is subsided at a bottom of the atomization chamber; then entering a powder storage with a protective atmosphere; after atomization, screening with a protective screening device before storing in the powder storage; and

f) loading the metal powder in the powder storage into a hot isostatic pressing capsule with inert gas protection; after fully vibration filled, evacuate-degassing the hot isostatic pressing capsule; and then sealing welding a capsuling end; finally providing a hot isostatic pressing treatment, in such a manner that the metal powder is fully consolidated, and completing powder metallurgy.

The above powder metallurgy comprises non-vacuum melting atomization and hot isostatic pressing processes with full-process protection to control the oxygen content and carbide morphology, and optimize a tool steel performance. The covering slag of the ladle is able to cut off the air and conductively heat. The inert gas is injected into the bottom of the ladle through the hole, so that temperatures at different positions of the liquid steel equals to each other, and harmful inclusions rapidly floats, thus being removed. The guiding tube at the bottom of the ladle guides the liquid steel as well as reduces turbulence fluid generated during flowing, so as to keep slag and inclusion out. Furthermore, the guiding tube prevents the liquid steel from being exposed to air, avoiding increase of an oxygen content of the liquid steel. The covering slag of the tundish prevents the liquid steel from being exposed to air when the liquid steel flows through the tundish, avoiding increase of the oxygen content. The tundish is pre-heated before the liquid steel enters, so as to avoid local condensation or early precipitation of a second phase when the liquid steel enters into the tundish. The powder storage has the protection atmosphere inside and a forced cooling function. The protective screening device protects a screening process and prevents the powder from flying. The powder storage is connected to the hot isostatic pressuring capsule in a sealed form, and the inert gas is injected into the hot isostatic pressing capsule before loading powder for discharging air, so as to control the oxygen content.

In summary, according to the present invention, a powder metallurgy tool steel with high wear resistance is obtained, which is also sufficient in impact toughness, bending strength and hardness. According to the embodiments of the present invention, the tool steel adapts certain chemical components and rapid cooling-consolidation process of the powder metallurgy, wherein a type of the MX carbide is (V, Nb) (C, N), in such a manner that the MX carbide precipitated is finer and a toughness of the tool steel is improved. After heat treatment, the hardness is more than HRC60, so as to satisfy different application requirements with a wide range of uses. The tool steel of the present invention is prepared according to the powder metallurgy, wherein a plurality of effective protection methods are used for keeping the liquid steel and the powder clean. Compared with conventional powder metallurgy tool steel, with a similar content of the MX carbide, the MX carbide of the tool steel of the present invention is finer and the tool steel is tougher.

For better understanding by the skilled person in the art, preferred embodiments of the present invention are illustrated as follows.

Preferred Embodiment 1

The preferred embodiment 1 refers to a group of powder metallurgy wear-resistant tool steels, whose chemical components are listed in Table 1.1:

TABLE 1.1

chemical components of powder metallurgy wear-resistant tool steels in the preferred embodiment 1

	C	Si	Mn	Cr	Mo	W	V	Nb	Co	S	N	O
embodiment 1.1	2.98	1	0.6	4.57	1.3	0.1	12.4	3	0.3	0.001	0.08	0.008
embodiment 1.2	3.38	0.89	0.3	5.26	1.8	0.1	13.1	1.15	0.3	0.001	0.06	0.0078
embodiment 1.3	3.98	1.5	1.3	5.45	2.4	0.7	15.9	2.6	0.4	0.005	0.5	0.008
embodiment 1.4	3.50	0.6	1.0	4.86	1.5	0.5	14.5	1.8	0.24	0.003	0.3	0.008

The powder metallurgy wear-resistant tool steels are prepared with a method comprising steps of:

a) loading liquid tool steal of the present invention into a smelting ladle with a load weight of 1.5-8 ton;

b) electrically heating covering slag at a top surface of the liquid steel in the smelting ladle by graphite electrodes, injecting argon or nitrogen gas from a hole at a bottom of the smelting ladle for stirring the liquid steel, opening a guiding tube when a liquid steel overheated temperature is 100° C.-200° C.;

c) moving the liquid steel into a tundish, which is pre-heated to 800° C.-1200° C., through the guiding tube at the bottom of the smelting ladle, controlling a size of an inlet of the guiding tube, in such a manner that a flow rate of the liquid steel is 10 kg/min-50 kg/min, adding a covering slag when the liquid steel enters into the tundish and buries a bottom end face of the guiding tube;

d) forming powder by atomization while continuously additional heating the tundish for maintaining the liquid steel temperature at 100° C.-200° C.;

e) moving the liquid steel into an atomization chamber through an opening at a bottom of the tundish, opening an atomizing gas nozzle, using nitrogen as an atomizing gas for atomization, wherein a nitrogen purity is ≥99.999%, an oxygen content is ≤2 ppm, a gas pressure is 1.0 MPa-5.0 MPa; cracking the liquid steel into drops by impact of an inert gas, while rapidly cooling into metal powder and depositing at a bottom of the atomization chamber; then entering a powder storage through the bottom of the atomization chamber; after atomization, waiting until the powder in the powder storage is cooled to a room temperature, and screening with a protective screening device; wherein an inert protective gas with a positive pressure is injected into a screening device chamber, and the powder storage has a protective atmosphere with a positive pressure inert gas; and

f) loading the metal powder in the powder storage into a hot isostatic pressing capsule, firstly injecting an inert gas into the hot isostatic pressing capsule for excluding air, then connecting the hot isostatic pressuring capsule and the powder storage in a sealed form; providing a vibration operation during loading for increasing filling density of the metal powder; then evacuate-degassing the hot isostatic pressing capsule while keeping a temperature at 200° C.-600° C.; degassing to 0.01 Pa and continuously heating for ≥2 h, and then sealing welding a capsuling end; finally providing a hot isostatic pressing treatment, with a temperature of 1100° C.-1160° C., and keeping a pressure of ≥1001 MPa for ≥1 h, naturally cooling after the metal powder is fully consolidated.

According to requirements, the tool steel of the present invention are further forged for obtaining certain shapes and sizes, and are treated with different heat treatments for obtaining different performances, wherein the heat treatments comprises annealing, quenching and tempering. Annealing comprises steps of heating a forging piece to 870° C.-890° C. and keeping the temperature for 2 h; cooling to 530° C. with a rate of ≤15° C./h; then cooling to below 50° C. by furnace cooling or static air cooling. Quenching comprises steps of pre-heating the forging piece after annealing at a temperature at 815° C.-845° C.; keeping the temperature at 1000° C.-1200° C. for 15-40 min after the temperature is even, then quenching to 530° C.-550° C., and cooling to below 50° C. Tempering comprises steps of heating the forging piece after quenching to 540° C.-670° C. and keeping the temperature for 1.5-2 h, then air-cooling to below 50° C.; repeating for 2-3 times.

According to embodiments 1.1-1.4, the powder metallurgy wear-resistant tool steels are obtained, wherein an increase of the oxygen content during process is ≤30 ppm. After hot working, a fully dense tool steel with a relative density of 100% is obtained, which is prepared into bars with a diameter of 50 mm.

Preferred Embodiment 2

The preferred embodiment 2 proves heat treatment hardness, impact toughness, bending strength, wear resistance, carbide content and particle size of the powder metallurgy wear-resistant tool steel of the preferred embodiment 1, wherein the carbide content and the particle size is analyzed based on structure images obtained by scanning electron microscope; and the heat treatment hardness, the impact toughness, the bending strength and the wear resistance are tested referring to GB/T 230.1, GB/T 229, GB/T 14452-93, and GB/T 12444-2006.

The powder metallurgy wear-resistant tool steel of the embodiments 1.1 and 1.2 are compared with a powder metallurgy tool steel (alloy A) and a forged tool steel (alloy B) bought, wherein results are as follows:

TABLE 2.1

components comparison between embodiment 1.1, embodiment 1.2, alloy A, and alloy B

	C	Si	Mn	Cr	Mo	W	V	Nb	Co	S	N	O
embodiment 1.1	2.98	1	0.6	4.57	1.3	0.1	12.4	3	0.3	0.001	0.08	0.008
embodiment 1.2	3.38	0.89	0.3	5.26	1.8	0.1	13.1	1.15	0.3	0.001	0.06	0.0078
embodiment 1.3	3.98	1.5	1.3	5.45	2.4	0.7	15.9	2.6	0.4	0.005	0.5	0.008
embodiment 1.4	3.50	0.6	1.0	4.86	1.5	0.5	14.5	1.8	0.24	0.003	0.3	0.008

According to the powder metallurgy wear-resistant tool steel of the embodiments 1.1 and 1.2, the oxygen content is 50-60 ppm before preparing and 60-80 ppm after preparing, which means the increase of the oxygen content is ≤30 ppm.

TABLE 2.2

heat treatment hardness, impact toughness and bending strength comparison between embodiment 1.1, embodiment 1.2, alloy A, and alloy B

	quenching method	tempering method	heat treatment hardness (HRC)	impact toughness a_k (J/cm^2)	bending strength σ_{bb} (MPa)
embodiment 1.1	1150° C. for 30 min	550° C. × 1.5 h × 3	61	20	3790
embodiment 1.2	1150° C. for 30 min	550° C. × 1.5 h × 3	62	19	4430
A	1150° C. for 30 min	550° C. × 1.5 h × 3	62	13	3860

TABLE 2.2-continued

heat treatment hardness, impact toughness and bending strength comparison between embodiment 1.1, embodiment 1.2, alloy A, and alloy B

	quenching method	tempering method	heat treatment hardness (HRC)	impact toughness a_k (J/cm^2)	bending strength σ_{bb} (MPa)
B	1000° C. for 15 min	200° C. × 1.5 h × 2	60	22	2600

According to Table 2.2, the powder metallurgy wear-resistant tool steels of the present invention have best combinations of strength and toughness.

TABLE 2.3

wear resistance comparison between embodiment 1.1, embodiment 1.2, alloy A, and alloy B

	quenching method	tempering method	hardness HRC	alloy mass loss (mg)
embodiment 1.1	1150° C. for 30 min	550° C. × 1.5 h × 3	61	15.7
embodiment 1.2	1150° C. for 30 min	550° C. × 1.5 h × 3	62	13.5
A	1150° C. for 30 min	550° C. × 1.5 h × 3	62	13.4
B	1000° C. for 15 min	200° C. × 1.5 h × 2	60	320

According to Table 2.3, wear resistances of the powder metallurgy wear-resistant tool steels of the preferred embodiments of the present invention are similar to that of the alloy A, and are far better than that of the alloy B.

TABLE 2.4

particle size comparison between embodiment 1.1, embodiment 1.2, alloy A, and alloy B

			MX carbide		M_7C_3 carbide	
	quenching method	tempering method	particle size µm	volume vol %	particle size µm	volume vol %
embodiment 1.1	1150° C. for 30 min	550° C. × 1.5 h × 3	0.5-1.3	16-25	NA	NA
embodiment 1.2	1150° C. for 30 min	550° C. × 1.5 h × 3	0.5-1.3	16-25	NA	NA
A	1150° C. for 30 min	550° C. × 1.5 h × 3	0.8-2.0	16-25	NA	NA
B	1000° C. for 15 min	200° C. × 1.5 h × 2	NA	NA	5-30	<16

Referring to Table 2.4, the carbide particle size refers to a size of carbide with at least 80% of volume content.

According to carbide analysis of the tool steel, carbide components of the powder metallurgy wear-resistant tool steels of the present invention and the alloy A are MX carbide. The type of the MX carbide of the present invention is (V, Nb) (C, N), which is mainly formed by V, Nb, C, N and a few alloy elements such as Fe and Cr. According to Table 2.4, the volume fraction of the MX carbide of the tool steel of the present invention is up to 16%-25%. Different from the alloy B, a huge amount of the MX carbide is conducive to a high wear resistance. The carbide particle sizes according to the present invention are really small, most of which is less than 1.3 µm while a biggest one is no more than 5 µm, which is conducive to a high toughness of the tool steel.

In summary, the powder metallurgy wear-resistant tool steels according to the present invention have excellent wear resistance, which are also sufficient in impact toughness, bending strength and hardness. After heat treatment, the hardness is more than HRC60, so as to satisfy different application requirements with a wide range of uses. For example, the tool steel is applicable to plastic machinery parts such as hard powder pressing, stamping die cutting, industrial cutting blades, wood cutting tools, wear parts, screws, screw sleeves, screw head. Compared with the conventional casting and forging tool steel, the present invention has advantages such as sufficient wear resistance and great increase of service life. Compared with the conventional powder metallurgy tool steel, with a similar content of the carbide, the tool steel of the present invention is tougher due to finer carbide. The powder metallurgy process of the present invention adapts a plurality of effective protection methods for keeping the liquid steel and the powder clean during preparation. The increase of the oxygen content during process is ≤30 ppm for ensuring a high-performance alloy material.

During description, words such as “first” and “second” are describing only without indicating importance or numbers of technical features. Therefore, “first” or “second” may refer to one or more features. During description, “a plurality of” refers to no less than two except for detailed illustration.

During description, references such as “one embodiment”, “some embodiments”, “an example”, “specific example”, or “some examples” mean that a particular feature, structure, material, or characteristic of the described embodiments or examples are included in at least one embodiment or example of the present invention. In the specification, the terms of the above schematic representation is not necessarily for the same embodiment or example. Furthermore, the particular features, structures, materials, or characteristics described in any one or more of the embodiments or examples are able to be combined in a suitable manner. One skilled in the art will understand that features in different embodiments or examples may be combined if not conflicting to each other.

One skilled in the art will understand that the embodiment of the present invention as shown in the drawings and described above is exemplary only and not intended to be limiting. It will thus be seen that the objects of the present invention have been fully and effectively accomplished. Its embodiments have been shown and described for the purposes of illustrating the functional and structural principles of the present invention and is subject to change without departure from such principles. Therefore, this invention includes all modifications encompassed within the spirit and scope of the following claims.

What is claimed is:

1. A powder metallurgy wear-resistant tool steel, comprising chemical components by mass percent of: V: 13.0%-16.0%, Nb: 1.2%-2.5%, C: 2.8%-3.7%, Si: ≤1.3%, Mn: 0.2%-1.5%, Cr: 4.8%-5.4%, Mo: ≤2.0%, W: 0.1%-0.5%, Co: 0.1%-0.4%, N: 0.05%-0.4%, O: ≤0.008%, with balance iron and impurities; wherein a carbide component of the powder metallurgy wear-resistant tool steel is an MX carbide with a NaCl type face-centered cubic lattice structure; wherein an M element of the MX carbide comprises V and Nb, and an X element comprises C and N;

wherein in the chemical components of the powder metallurgy wear-resistant tool steel, a V equivalent is V_{eq}: 13.0%-16.0%, wherein V_{eq}=V+0.65 Nb.

2. The powder metallurgy wear-resistant tool steel, as recited in claim **1**, wherein the impurities comprise S, wherein a S content is no more than 0.1%.

3. The powder metallurgy wear-resistant tool steel, as recited in claim **2**, wherein the impurities comprise P, wherein a P content is no more than 0.03%.

4. The powder metallurgy wear-resistant tool steel, as recited in claim **3**, wherein a volume fraction of the MX carbide is 16%-25%.

5. The powder metallurgy wear-resistant tool steel, as recited in claim **4**, wherein a size of at least 80% of the MX carbide is 0.5-1.3 μm judging from volume percentage.

6. The powder metallurgy wear-resistant tool steel, as recited in claim **5**, wherein a maximum size of the MX carbide is no more than 5.0 μm.

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